# Study to Distributed Generation Deployment Using Photovoltaic System Connected in a Grid Residencial Consumer

Oswaldo Hideo Ando Junior [*1], Ricardo Macan[2], João Mota Neto[3], Mario Orlando Oliveira[4], Jose Horacio Reversat[5], Roberto Chouhy Leborgne[6]

[*1,2,3]Department of Electrical Engineering, Faculdade SATC

Criciúma, Santa Catarina, Brazil

[4,5]Energy Study Center to Development (CEED), National University of Misiones–UNaM,

Oberá, Misiones, Argentina.

[6]Department of Electrical Engineering, University Federal of Rio Grande do Sul – UFRGS

Porto Alegre, Rio Grande do Sul, Brasil

[*1]oswaldo.junior@satc.edu.br; [2]ricardo_macan@hotmail.com; [3]joao.neto@satc.edu.br
[4]oliveira@fio.unam.edu.ar; [5]hreversat@fio.unam.edu.ar
[6]rcl@ece.ufrgs.br

***Abstract***

*This paper presents a study on Photovoltaic System (PVS) and implementation on the electric network in a residential consumer. In this sense, the rules and regulations for this type of Distributed Generation (DG) are presented. For this application two possible solutions are selected, the first with a PV system connected to the network with 18 photovoltaic modules monocrystalline silicon, providing a power of 245 Wcc, and the second solution formed for a PVS connected to the network with 15 photovoltaic modules of 290 Wcc. The proposed solution validation is carried out using the simulation software System Advisor Model (SAM). Finally, the analyses results of possible solutions for the deployment of photovoltaic system are presented.*

***Keywords***

*Distributed Generation, Solar Energy, Photovoltaic System; Normalitation.*

## Introduction

In the Brazilian electrical system, most power generation comes from hydro (approx. 72%) which explains the large number of distribution and transmission lines needed to carry the electric power to the consumer centers (Ministério M. E.,2011).

The need for implementation of energy generation systems, has been commonly recognized with that new renewable sources will be explored, and both consumers and electrical system will benefit as this new source of clean generation willbe contributive without environmental degradation.

The continuing advancement of industrial and the population pressure have generated a considerable increase in the electricity demand, which forced the electric companys to expand plants generators and build new transmission and distribution lines. Given this scenario, new alternatives to energy generation have arisen, such as the Photovoltaic Systems Connected to Network (PVSCN), where the generators are located near the consumption centers.

This paper presents a study on Photovoltaic System (PVS) implementation on the distribution network. This work begins with an overview of the Distributed Generation (DG), as well as their advantages and disadvantages, mainly highlighting the steps to deploy PVSCN. Thus, a case study is presented in this paper for implementation of a PVSCN in a residence located in Criciúma city –SC, Brazil.

## Distributed Ganeration

### *Distributed Generation Concept*

Distributed Generation, also called decentralized generation, is not a concept got full consensus among experts, ie, there are different definitions related to the concept of DG in various countries (Ackermann, T., Anderson, G., Söder, L., 2001).

In this work the brazilian reglamentation defined in PRODIST Module 3- Access to Distribution System will be adopted, approved on 16 December 2008 by

Resolution No. 345, ( ANEEL, 2012): *"DG are electric energy generator centrals with installation connected directly on distribution systems or installations of the consumer, opering in parallel or isolated of the electric network and dispatched or not by the National Electric System Operator (ONS)"*.

To standardize the connection of the generator plants in the electricity grid, the necessary protections are stipulated by PRODIST in Module 3, the supply voltage in function of the power levels installed for micro and mini distributed generation, which are indicated in Tab. 1.

TABLE 1 VOLTAGE LEVEL IN FUNCTION OF THE POWER INSTALLED.

| Conection Voltage Level | Power InstalLed |
|---|---|
| Low Voltage<br>(single-phase, bi-phase or three-pashe) | < 10 kW |
| Low Voltage (three-phase) | 10 a 100 kW |
| Low voltage (three-phase) /<br>Medium voltage | 101 a 500 kW |
| Medium Voltage / High Voltage | 501 a 1 MW |

The voltage level connection in the electric grid is set by the local utility in function to limite the network. The mini and micro distributed generation are so named because of its installed capacity in the network, and the use of subsidized sources of power generation such as solar, wind, among other ones. Since the micro-generation has a power lower or equal to 100 kW and mini-generation has a power higher than 100 kW and less than or equal to 1 MW. ( ANEEL, 2012).

### *Deployment Vantages of the DG*

DG is a way to give more certainty as to the supply of electricity, because with DG has increased in the availability electric power for small periods compared to large hydropower plants,, which has a deployment time 6-8 years. In locations where the circuits are too large or at the end of lines, there are problems of voltage drop. In this context, the GD can contribute positively to the quality of this energy, increasing tension levels in these excerpts.

The DG insertion also alleviates the need for construction of new power plants and large transmission as well as distribution lines. The energy supply can help alleviation of the transmission and distribution systems in cases where it has overloads, thus postponing investments expanding the transmission and distribution systems (Cardoso, G.S., 2009).

One of the major motivations to conduct this study is the Normative Resolution No. 482/2012 that ANEEL approved in April 2012, where consumers who produce their own electricity earn credits valid for 36 months by the surplus that is injected into the local utility grid, further lowering the barriers to the deployment of GD (ANEEL,2012).

### *Deployment Disadvantages of the DG*

Currently the electric distribution system has a radial configuration and unidirectional, which would require adjustments in protection systems that support for bidirectional flows, presenting a greater complexity in the planning and operation of the electrical system, reconfiguring all protection in reaction to this new condition. With this bidirectional flow in the distribution network caused by the deployment of distributed power, some features such as short circuit levels and harmonic distortions change, undermining the current system and causing a need for significant costs.

The number of overvoltages caused by stringent safety levels that are made by the owners to protect their generators, also increases, as increment in the number of automatic shutdown of its generators, changing important system characteristics, such as stability and regulation tension (Gonçalves, L.F., 2004).

As nowadays existing technologies in the trade are still at a premature level, the costs for the initial deployment of systems with GD are still high.

## PVSCN Characteristic

The photovoltaic system was initially developed for very specific applications, such as in space satellites. However, after the oil crisis in the 70s, photovoltaics received many financial incentives for both private and public sector, these incentives havecontributed to the growth of this type of energy generation. In 2005, this sector grew by 67% worldwide, compared to the last five years (Imhoff, J.,2007).

### *Solar Radiation*

Solar radiation is one of the main factors that influence the electrical characteristics of photovoltaics, ie, the current generated proportional to the radiation incident about photovoltaic panel. In Figure 1, the output characteristics of a photovoltaic panel in relation to solar radiation. may be noted (Imhoff, J.,2007).

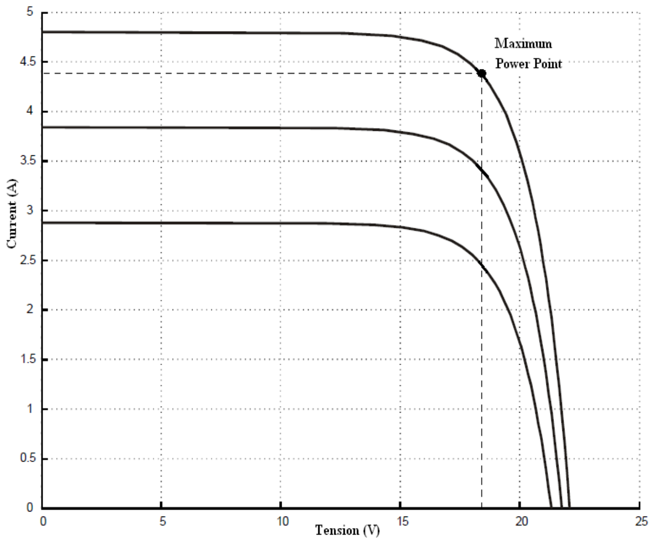


FIG. 1 OUTPUT CHARACTERISTICS OF PHOTOVOLTAICS PANELS IN FUNCTION OF SOLAR RADIATION

Brazil has one of the best indices of solar radiation, where the part with less solar radiation is about 40% higher than the sunniest place in Germany, which is currently the country which excels in power generation through photovoltaics . Brazilian indices of solar radiation can be seen in Figure 2. (Christante, L., 2012).

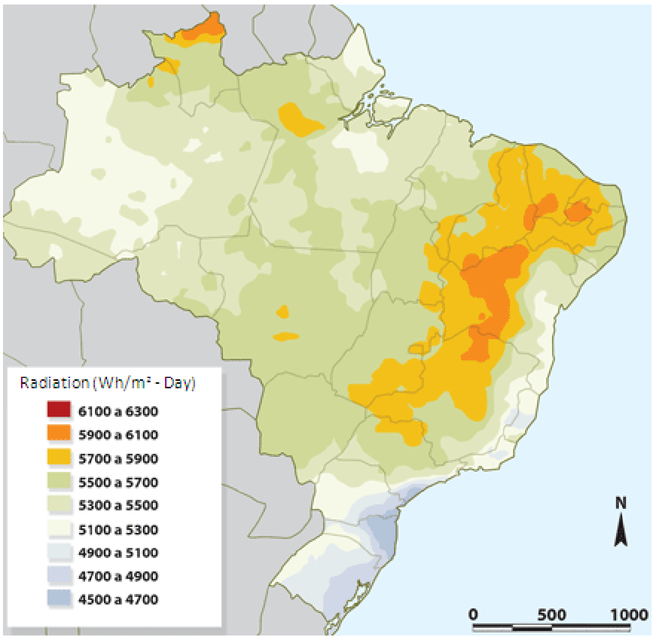


FIG. 2 SOLAR RADIATION ON BRAZILIAN TERRITORY

### *PVSCN Definition*

The PVSCN , a complementary form of power generation through an inexhaustible source of energy: the sun, is split into two basic types: those connected centrally to the electric grid, and those connected in a decentralized network, namely close to the load, which is the focus of this work.

In the decentralized form, roofs or facades of houses and buildings are the basis for photovoltaic panels which are responsible for the capture and conversion of solar energy into DC electricity, which is converted to AC by means of an inverter DC / AC .

### *Main Components*

Due to changes in power flow, some devices must be applied to the power system in order to synchronize and harmonize the physical quantities such as voltage, current, frequency, etc.. between the photovoltaics system and electrical distribution system. Thus, in this chapter the main devices that comprise a PVSCN will be discussed.

#### *1) Photovoltaics Arrangement*

Consisting of one or more photovoltaic modules connected together electrically, these modules are formed by a set of photovoltaic cells connected in series or in parallel, which are the devices responsible for direct conversion of solar energy into electrical energy (Viana, T. S., Rüther, R.,2007). These photovoltaic cells are usually made of semiconductor materials, usually silicon, and the conversion of solar energy into electrical energy occurs through a process known as the photovoltaic effect (Câmara, C.F., 2012).

#### *2) CC/CA Inversor*

It is the device responsible for the adequacy of the DC power generated by PV modules into AC power, synchronizing the voltage, current and frequency with the existing power grid of the local utility. The inverters control the whole process, for example, conversion DC to AC, the power flow, the manual or automatic disconnect with the grid, the operational data logging, protection devices (anti-islanding protection, against overload and overvoltage, among others) (Câmara, C.F., 2012). Therefore, when an inverter DC/AC is sized, it is very important to note that the chosen model meets the loads to be fed and if has all the functions that a PVSCN requires (Rodriguez, C.R.C., 2002).

#### *3) Bidirectional Meter*

When a DG central is injected into the network, the network is exposed to a bidirectional flow of current, since the autoproducer can consume energy from the grid utility local (if their generation is less than demand consumed), as well

the DG grid can inject the surplus (if your generation is greater than demand consumed). Thus, a control system requires a energy compensation system, where a meter will register this bidirectional power flow.

#### 4) *Electric System Protection*

Always that it is "work" with electricity, either in the generation, transmission, or distribution, some protections are needed to ensure both perfect functionality of the system and the integrity of the people who have access to the system. In order to isolate the photovoltaics inversor system, a protection system is used with switch fuse and connectors, and this protection is designed to allow the maintenance or replacement of the inverter DC/AC safely. Among the protections in CA, depending on the inverter to be installed, they may have already been embedded in every device, so when designing the inverter is important for analysis of existing protections in it, there is no need for the additional expenses with other protections (Câmara, C.F., 2012).

### *Cost Estimating*

The costs for implementing SFCR in Brazil are still one of the greatest barriers, as among the main components of this system that are the photovoltaic panels and inverters DC/AC, both of which are imported from other countries, implying higher costs, due to high taxes and the fact that in Brazil there is still no large investments in photovoltaics.

Figure 3 shows the costs in Europe, where the price of Euros to Dollars was referenced to 05 November 2012. As it can be seen that there has a variation in costs according to the potency of the components.

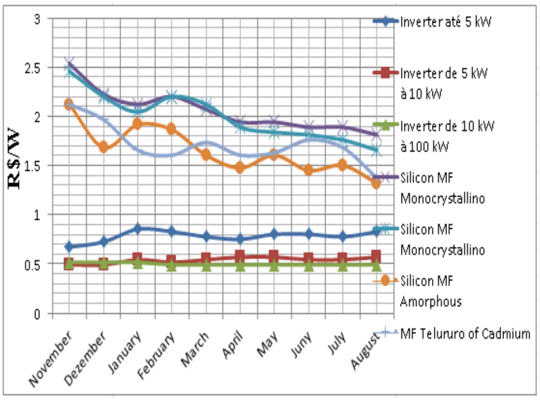


FIG. 3 PHOTOVOLTAICS MODULES AND INVERSOR COSTS BY HIS POWER

In Brazil, the cost of power generation through the low-power equipment is high, i.e, a residence expenses on average 550 kWh per month has a cost t of he BRL 602/MWh and the average cost of installation of the photovoltaic system with low power revolves around BRL 38,000 (Uchôa, B., 2012).

### Rules and Regulations for PVSCN

Until the 90s, Brazil still had no entity to regulate and supervise electricity, without standardization and control of power supply. Then, on December 26, 1996, the National Electric Energy Agency (ANEEL) was established, through Law 9427, in charge of the regulation and control of the generation, transmission, distribution and sale of electricity in Brazil . ANEEL, in turn, has developed various normative resolutions to ensure the quality of power supply and the operation of the electric system, among which established by ANEEL, none was no specification on the interconnection of DG in power grid (Cardoso, G.S.,2009).

However, on December 16, 2008 the first version of PRODIST came into force through Normative Resolution No. 345, which normalizes and standardizes the relationship between distributors and other agents connected to the distribution system. And recently, still in the approval stage, it is the second draft prepared by Norma :082.01 EC-03-001 (Study Committee Systems Photovoltaic Solar Energy Conversion) of ABNT/CB-03 (Brazilian Committee of Electricity ), which standardizes the characteristics of photovoltaic systems with connection to the power grid distribution in Brazil.

Nowadays, the latest versions in terms of regulations and procedures for the interconnection of distributed generation in distribution grid include: PRODIST, and second ABNT Project, which focuses on PVSCN. The PRODIST is a document divided into 9 modules, and the main for this work is the module 3 which deals with access to the distribution system, where its stages can be seen in Table 2.

Table 2 shows the steps to access the grid's distribution, section 3.7 of Module 3 of PRODIST, which brings the procedures for access of micro and mini distributed generators.

In addition, the second draft standard ABNT 03:082.01-001 aims to standardize the interface characteristics of photovoltaic systems with connection to the power grid distribution, as well as the minimum

requirements to get a good quality power.

TABLE 2 DISTRIBUTION ELECTRIC SYSTEM ACCESS (STEPS)

| Stage | Action | Responsible | Term |
|---|---|---|---|
| 1 Access solicitation | (a) Formalising access request, with routing of documents, data and relevant information, as well as studies performed. | Autoproducer | - |
| | (b) Receipt of the access request. | Electric Company | - |
| | (c) Settling issues related to information received. | Autoproducer | Until 60 days after the action 1 (b). |
| 2 Opinion to Access | (a) Opinion on the definition of access conditions. | Electric Company | i. If there is need for works until 30 days after the action 1 (b) or 1 (c). |
| | | | ii. For mini generators distributed, requiring works until 60 days after the action 1 (b) or 1 (c). |
| 3 Contracts | (a) Signing of contracts, when applicable. | Autoproducer and Electric Company | Until 90 days after the action 2 (a). |
| 4 Connection Implementation | (a) Request for inspection. | Autoproducer | Defined for autoproducer. |
| | (b) Achievement inspection. | Electric Company | Until 30 days after the action 4 (a). |
| | (c) Delivery to the autoproducer the survey report. | Electric Company | Until 15 days after the action 4 (b). |
| 5 Connection Point Approval | (a) Adequacies of the limitations of the inspection report. | Autoproducer | Defined for autoproducer. |
| | (b) Approval of the connection point, freeing it to their effective connection. | Electric Company | Until 7 days after the action 5 (a). |

According to the second draft standard ABNT 03:082.01-001, a PV system can be interconnected to the distribution networkand must meet certain parameters (voltage, frequency, total harmonic distortion, power factor, etc.), to obtain a better quality of electricity supply. Being that if at any time the power supplied does not meet these parameters, the SF must stop the power supply in accordance with the times set by the standard, with the purpose of operating times being that the SF does not interrupt the power supply in case of disturbances of short duration.

## Case Study

This paper presents a preliminary design of a SF, integrated grid electrical distribution in a residential consumer, where they will raise all the data necessary for such implementation, as well as demand consumed by the residence, the area available for allocation panels photovoltaic, solar radiation that falls on the roofs of the residence, the necessary power to be generated by the PV system to meet all the demand consumed by the residence, among other information.

### *Description of Location*

The study site for the implantation of SF is a residential consumer. This residence is located in Criciúma, south of Santa Catarina. Since the chosen area has dimensions of 11.2 x 3.5 meters, with an area of 39.2 m². An important fact to be noted is that the roof of the residence is submitted the irradiance, which ensures a better use of SFCR.

The analysis on the potential areas of residence for installation of photovoltaic modules, has been identified that this area is the best option to instal modules because the same is oriented approximately -10° north and the roof has a gradient of approximately 14.9°. Note then that the roof has a great position to harness solar energy.

### *Electric Power Consumption*

The average monthly and daily consumption of electricity of the residence is determined through historical consumption, which is presented in Fig. 4.

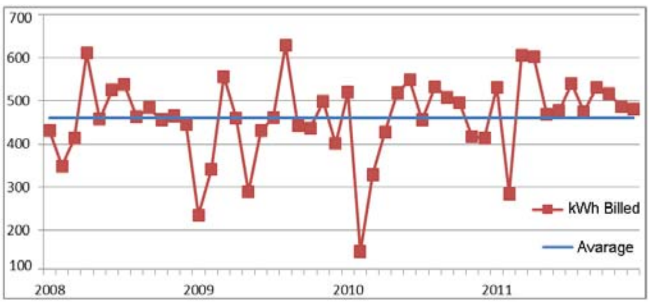


FIG. 4 CONSUMED DEMAND FOR RESIDENCE

As displayed, the average monthly total consumption

during January 2008 to December 2011 was 460.94 kWh and consequently the average daily total consumption was 15.36 kWh.

*Rated Power Needed*

Using (1), the calculation of nominal power needed to supply the average daily consumption of residence may be made. To perform the calculations, you must have knowledge of some variables such as the average daily consumption of the residence, the daily gain of solar radiation and system efficiency, which depends on the inverter to be used in the project [20].

$$Pcc = \frac{(E/G_{poa})}{R} \quad [kWp] \qquad (1)$$

Where:

Pcc [kWp]: Average power needed;

E [kWh]: Average daily consumption;

Gpoa [kWh/m2/dia]: Gain by solar radiation: average monthly of daily total; and

R[%]: System efficiency.

As seen in Fig. 4 and Fig. 2, the values of daily consumption and gain by solar radiation are respectively 15.356 kWh and 4.8 kWh/m2 per day. However, considering an increase in demand consumed in the coming years, an average daily value of 17 kWh is considered, resulting in an average annual consumption of 6120 kWh.

Since overall efficiency of the system also depends on the inverter, an approximate value of 83% has been taken into account which is the average of photovoltaic systems of this size, evidenced through prior simulation of the system.

From the acquired data, and (1), the approximate power value is 4.27 kWp.

*Simulations*

The software used for simulations of this case study is the System Advisor Model (SAM). This software is used to simulate various types of renewable energies and present financial options, meaning that the user can still have an estimate of project costs.

*1) Simulation Modules with Monocrystalline Silicon*

First is adopted photovoltaic module SPR-245NE-WHT-D produced by Sunpower Corporation.

A great advantage of Sunpower Corporation is the high efficiency of its photovoltaic panels, around 19%, with optimum efficiency compared to other brands available in the SAM software. Data from the photovoltaic module can be seen in Table. 3.

TABLE 3 CHARACTERISTICS OF PHOTOVOLTAIC MODULE

| Electrical Characteristics | |
|---|---|
| Efficiency | 19,70% |
| Maximum Power | 245,025 Wcc |
| Maximum Voltage DC | 40,5 Vcc |
| Maximum Current DC | 6,05 Acc |
| Open Circuit Voltage | 48,8 Vcc |
| Short Circuit Current | 6,43 Acc |
| **Physical Characteristics** | |
| Number of Cells | 72 |
| Area of Module | 1,244 m² |
| **Material** | Monocrystalline silicon |

To make the conversion of solar energy into electrical energy, inverter PVI-4.6-OUTD-I-US-x-y is adopted, produced by Power-One, in which the main electrical characteristics of the inverter are presented in Table. 4.

TABLE 4 ELECTRICAL CHARACTERISTICS OF INVERTER

| Electrical Characteristics | |
|---|---|
| AC Voltage | 240 V |
| AC Power | 4600 Wac |
| DC Power | 4779,58 Wcc |
| Maximum Voltage DC | 520 V |
| Maximum Current DC | 14 A |

Order to optimize the installation of the photovoltaic system is made, before all the characteristics of the system components have taken into consideration, because each component, as seen in Table 3 and Table 4, has its limitations, voltage, electric current and power.

Orders for these limitations respected must be made between series and parallel combinations photovoltaic modules, since the voltage and current of the system increases due to the sum of the voltages in the series circuit and the sum of the electric currents in the parallel circuit.

Thus, considering the electrical characteristics of the components and the physical characteristics the installation location, 18 photovoltaic panels are used to power 245.025 Wcc, and these panels have been organized in 9 modules per line with two parallel lines. Also, it has left a space between modules for future maintenance, and so there is no shading caused by the photovoltaic modules. The results from this array may be analyzed in Figure 5.

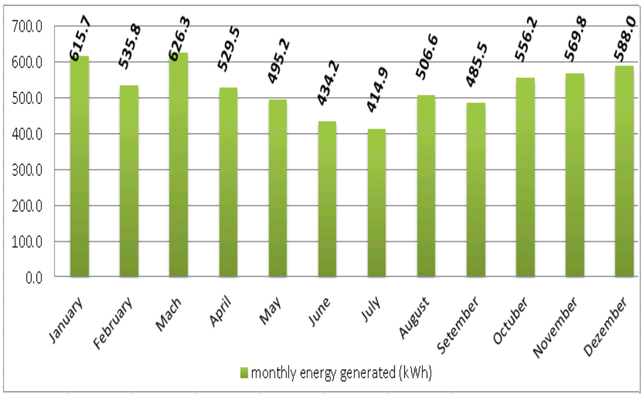


FIG. 5 PHOTOVOLTAIC GENERATION OF MONTHLY ARRAY

Based on the Figure 5, it is noted that the annual generation of this photovoltaic system is 6357.7 kWh, supplying in this manner the average annual consumption of 6120 kWh of residence, as with the increase in demand in the coming years.

### 2) *Simulation modules with multicrystalline silicon*

On this second simulation photovoltaic modules are selected produced by Siliken Canada. The technology of these modules is based on Multi-c-Si (multicrystalline silicon). Information of photovoltaic modules may be seen in Table 5.

Order to make the conversion of solar energy in electric energy adopts the same inverter PVI-4.6-OUTD-I-US-x-y, produced by Power-One, in which the main electrical characteristics of the inverter are presented in Table 4.

TABLE 5 CARACTERÍSTICAS DO MÓDULO FOTOVOLTAICO

| Electrical Characteristics | |
|---|---|
| Efficiency | 14,96% |
| Maximum Power | 290,128 Wcc |
| Máximum Tension CC | 35,73 Vcc |
| Máximum Current CC | 8,12 Acc |
| Open Circuit Voltage | 44,4 Vcc |
| Short Circuit Current | 8,61 Acc |
| **Physical Characteristics** | |
| Number of Cells | 72 |
| Area Module | 1,94 m² |
| Material | Multicrystalline Silicon |

In this simulation, 15 photovoltaic panels are used to power 290.128 Wcc, which arranged in 5 modules per line with three lines in parallel. Here also a space is left between the modules for maintenance and avoidance of shading of the panels themselves. The results obtained from this photovoltaic modules array may be analyzed in Figure.6

Based on the Figure 6 it can be seen that the annual generation of this photovoltaic system is 6227.7 kWh, supplying in this manner the average annual consumption of 6120 kWh of residence, now with the increase in demand in the coming years.

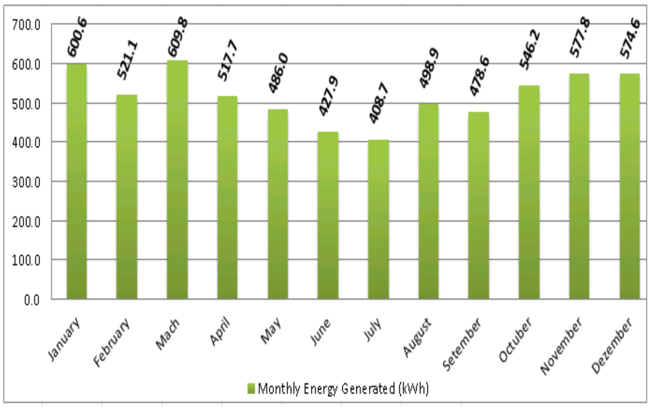


FIG. 6 PHOTOVOLTAIC GENERATION OF MONTHLY ARRAY

## Result Analysis

Based on the results of simulations of photovoltaic arrays on SAM software, technical analysis is, in this section, the reader exposed.

In the first simulation, it uses the photovoltaic module technology of monocrystalline silicon Sunpower Corporation, and in the second the photovoltaic module technology of multicrystalline silicon Siliken Canada is employed.

According to the obtained results, it is perceived that both configurations simulated of consumption and demand of electric power residential, however, the second configuration requires an area greater than the former. This occurs due to that the technology of monocrystalline silicon has an efficiency greater than that of multicrystalline silicon, requiring then a lower area to generate the same energy.

Regarding the area, the first photovoltaic module array occupies one effective area of 21.58 m², but with the spacing between modules, this area increases to 32.81 m². While the second photovoltaic module array, occupies an effective area of 28.51 m², however, with the spacing between modules, this requires an area of 38.21 m².

While with respect to the configuration, the first arrangement consists of two parallel lines with 9 modules in series, resulting in 18 photovoltaic panels, whereas the second arrangement consists of three lines in parallel with five modules in series, resulting in 15 photovoltaic panels .

Information generation and annual energy

consumption may be seen in Figure. 7.

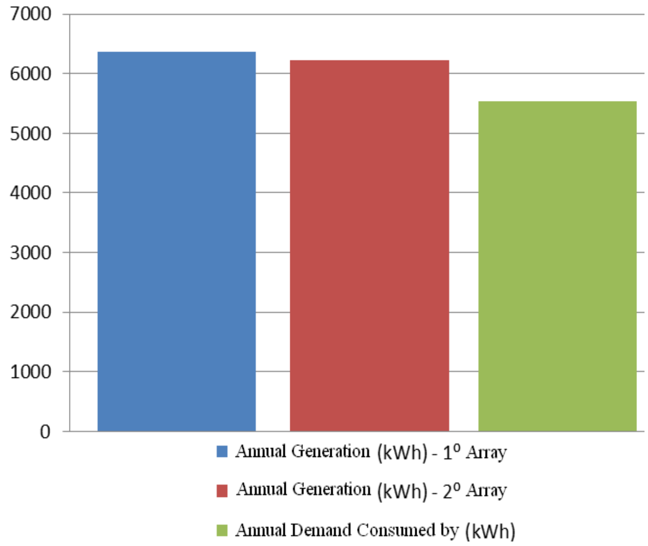


FIG. 7 ANNUAL COMPARISON BETWEEN GENERATION AND CONSUMPTION

Figure 7 shows the annual power generation of both SF projected and simulated compared with the mean annual residence. Asit can be observed in both cases that the power generation exceeds consumption, even with the increased demand expected in the coming years. So through the results it is revealed that the residence becomes self sustainable from the deployment of photovoltaic systems, having a surplus of energy that may be injected into the power grid, generating credits for the autoproducer, and these credits can be used during periods when the demand generation is less than consumed, normally in winter.

The inclination the photovoltaic modules is made basically for two reasons, first for that there is a refrigeration system, and so the panels do not lose efficiency because the increase of temperature, and second that the inclination angle of the system relative to the sun can be adjusted, because more photovoltaic panels are perpendicular relative to the sun, the larger the use of solar energy.

Both simulations have adopted an inclination of 26.4° in the north, considering the roof pitch. This inclination have been thus adopted through various simulations in the SAM software, and this value has obtained as the best slope value for this location because it is this angle that the solar rays have greater perpendicular incidence in photovoltaic panels during the year , thus reaching excellent performance of the same, and consequently the generation electricity is increased.

## Conclusions and Future Work

The focus of this paper is on the consolidation of knowledge to implement a type of GD to connect at of this grid, SF. Thus, during the work, the functioning of a SFCR and surrounding devices, necessary protections, the cost of the main components of this system of power generation, norms and regulations for GD have been presented.

Some factors that contribute to Brazil to have difficulty in GD deploying the grid are the complexity of adapting conventional structures of distribution system, in which they are prepared only for a unidirectional flow of electricity and these grid must adapt to this new situation, as well as protections necessary to ensure the perfect system functionality and integrity of the personnel involved, with a bidirectional direction of power, and especially the insignificant amount of incentive mechanisms of government with the purpose of establishment of a GD in the Brazilian electric sector.

Thus, progress and increase of SFCR in Brazil, depend on the advancement of existing technologies in these systems, the progress in industrial and commercial sector, and especially the incentives provided by the government to reduce investment costs.

## REFERENCES

Ackermann, T., Anderson, G., Söder, L. Distributed Generation: A Definition. Electric Power Systems Research, vol. 57, p. 195-204. 2001.

ANEEL. Resolução Autorizativa nº. 482, de 17 de abril de 2012. Disponível em: http://www.aneel.gov.br/cedoc/ren 2012482.pdf. Acessado em: 01 ago. 2012.

Câmara, C.F. Sistemas Fotovoltaicos Conectados à Rede Elétrica. 2011. 68 f. Monografia (Pós-Graduação em Formas Alternativas de Energia). Universidade Federal de Lavras. Lavras, 2011.

Cardoso, G.S. Uma visão crítica do cenário da Geração Distribuída no Brasil. 2009. 136 f. Dissertação (Mestrado em Programa de Pós-graduação em Energia). Universidade Federal do ABC. Santo André, 2009.

Gonçalves, L.F. Contribuições para o estudo teórico e experimental de sistemas de geração distribuída. 2004. 156 f. Dissertação (Mestrado em Engenharia Elétrica). Universidade Federal do Rio Grande do Sul. Porto Alegre, 2004.

Ministério de Minas e Energia. Resenha Energética Brasileira, 2011.

Imhoff, J. Desenvolvimento de Conversores Estáticos para Sistemas Fotovoltaicos Autônomos. 2007. 146 f. Dissertação (Mestrado em Engenharia Elétrica). Universidade Federal de Santa Maria. Santa Maria, 2007.

Viana, T. S. e Rüther, R. Análise do Desempenho de um Sistema Fotovoltaico de 10kWp Conectado à Rede Elétrica. In: I Congresso Brasileiro de Energia Solar. Fortaleza, Ceará. 2007.

Rodriguez, C.R.C. Mecanismos Regulatórios, Tarifários e Econômicos na Geração Distribuída: O Caso dos Sistemas Fotovoltaicos Conectados à Rede. 2002. 135 f. Dissertação (Mestrado em Engenharia Mecânica). Universidade Estadual de Campinas. Campinas, 2002.

Uchôa, B. Energia Solar é bom negócio e prática só traz economia para o consumidor. O Fluminense Rio de Janeiro, 17 jan. 2012.

**Oswaldo Hideo Ando Junior** majored in Electrical Engineering and specialization in Business Management from the Lutheran University of Brazil-ULBRA with a Masters in Electrical Engineering at the Federal University of Rio Grande do Sul–UFRGS. Currently, he is lecturer of Electrical Engineering, Faculty SATC. Reviewer ad hoc FAPESC and PMAPS. His work interests are mainly in the areas: Energy Conversion, Power Quality and Power Systems..

**Ricardo Macan** majored in Eletric Engenier (2012) in Faculty SATC.

**João Mota Neto** graduated in Industrial Automation Technology at the University of Southern Santa Catarina and received master's degree in mechanical engineering-UFRGS. Currently, he is lecturer of electrical engineering and industrial automation technology in the Faculty SATC Developing research in the areas of energy efficiency, instrumentation and automation.

**Mario Orlando Oliveira** (M'09) was born in Capiovi, Misiones, Argentina, on May 13, 1979. He received the Eletromechanical Engineering degree from the National University of Misiones (UNaM), Argentina, in 2005 and M.Eng. degree from the Federal University of Rio Grande do Sul (UFRGS), Porto Alegre, Brazil, in 2009. Currently, he is researcher of the Energy Study Center to Development (CEED) and auxiliary professor of the UNaM. His research interests include electrical machines protection and modeling, faults detection and location.

**Jose Horacio Reversat** was born in Jardin America, Misiones, Argentina, on November 25, 1963. He received the Electrical Engineering degree and Plant Production Specialist from the National University of Misiones (UNaM), Argentina, in 1996 and 2000 respectively. Currently, he is researcher of the Energy Study Center to Development (CEED) and professor of the UNaM. His research interests include electrical machines protection and electrical measurements.

**Roberto Chouhy Leborgne** Graduated in Electrical Engineering from the Federal School of Engineering Itajubá (1998). He received Electrical Engineering degree from the Federal University of Itajubá (2003) and Ph.D. in Electrical Engineering from Chalmers University of Technology (2007). Has experience in Electrical Power Systems, with emphasis on Power Quality. He is currently Adjunct Professor at the Federal University of Rio Grande do Sul.